

Velocities

Agenda

- Objectives
- Introduction
- definitions & equations
- Normal Moveout
- Dips / Stretch
- Velocity Analysis

At the end of this Session, you will be able to:

- Define RMS, Interval, NMO, Stacking average & apparent Velocities.
- Understand how Interval velocities can be calculated from RMS velocities
- Define the term 'Normal Moveout' as used in data processing.
- Define the term 'NMO correction'
- Produce a diagram that shows how a single primary event on a CMP gather would appear for each of the following: no NMO correction, NMO correction using too high velocity, NMO correction using too low velocity, NMO correction using correct velocity
- Define the term 'NMO stretch'

At the end of this Session, you will be able to:

- **Define the term 'velocity pick' as used in velocity analysis.**
- **Define the term 'knee point' as used in velocity function estimation.**
- **Define the term 'semblance' as used in velocity analysis.**
- **Define the term 'multi velocity function stack' as used in velocity analysis.**
- **Define the term 'constant velocity stacks' as used in velocity analysis.**
- **Define the term 'constant velocity gathers' as used in velocity analysis.**
- **Define the term 'whole line constant velocity stacks' as used in velocity analysis.**
- **Define the term 'NMO corrected CMP gather' as used in velocity analysis.**
- **Describe criteria that are used to justify the selection of a primary energy 'velocity pick' for each of the following: semblance display, NMO corrected gather, constant velocity stack, multi velocity function stack, constant velocity gather.**

At the end of this Session, you will be able to:

- **Describe at least 3 characteristics that can differentiate primary and multiple energy during velocity picking.**
- **Describe at least 3 characteristics of geology and seismic data that influence location of velocity analyses.**
- **Define the term 'horizon consistent picking' as used in velocity analysis.**
- **Define the term 'isotime consistent picking'**
- **Define the term 'isovelocity plot' as used in velocity analysis.**
- **Define the term 'velocity inversion'**
- **Describe at least 3 factors that dictate whether velocity inversions are acceptable to a given data processing project.**
- **List 5 products used as QC tools for velocity picking**

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Why is velocity important ?

- Identifying rock type
- Amplitude compensations
- Static corrections
- Common-midpoint stacking
- Migration
- Depth conversion

Is it the same velocity in all cases?

- No

- For Amplitude Compensation we require the interval velocity model
- For Stacking, we require the Stacking Velocity
- For migration, we require a realistic interval velocity model which may be smoothed (heavily) for time migration
- For Depth imaging, we require the interval velocity model

So where do we start?

- **Amplitude compensation in the form of geometric spreading is 'lucky' in that it is reversible, so if we use the wrong velocity, later we can back it off & then redo with a better one - often done.**
- **So make an estimation, correct the data, do further processing and then run VELOCITY ANALYSIS.**

So where do we start?

- **Amplitude compensation in the form of geometric spreading is 'lucky' in that it is reversible, so if we use the wrong velocity, later we can back it off & then redo with a better one - often done.**
- **Typically a simple, spatially invariant, function is used to start. Later it can be backed off and a more accurate, perhaps spatially variant, field can be used.**

Agenda

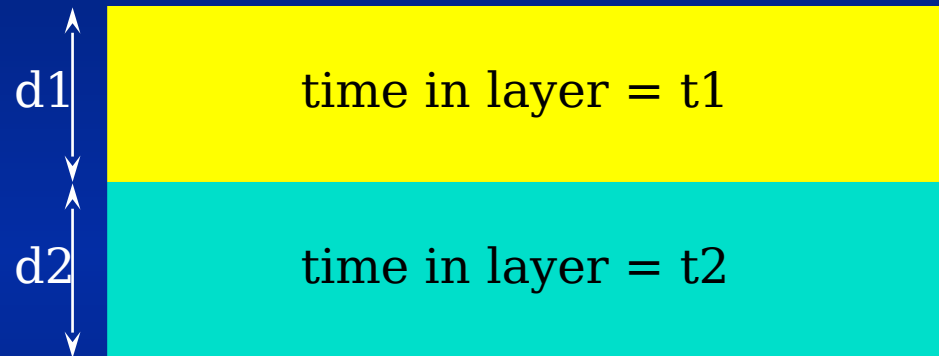
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- **Understand how Interval velocities can be calculated from RMS velocities**

Average Velocity

The distance traversed divided by the time required.

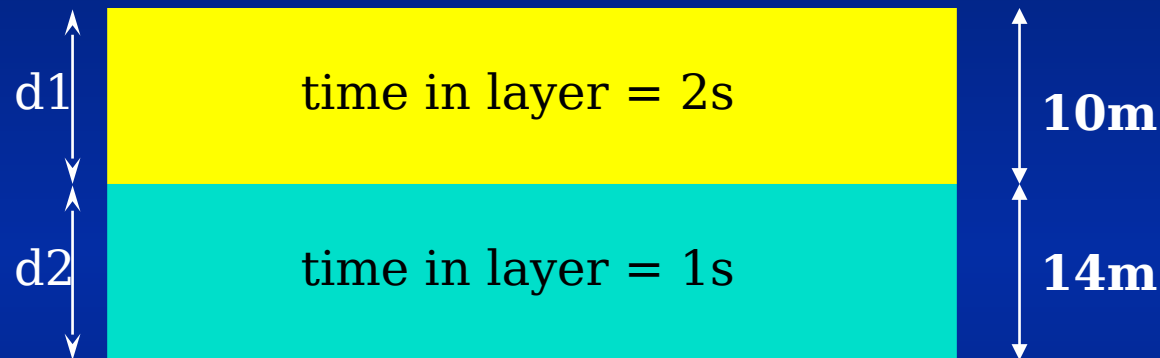


$$V_a = \frac{d_1 + d_2 + \dots}{t_1 + t_2 + \dots}$$

Often (but not always) assuming straight ray-path

Average Velocity

The distance traversed divided by the time required.



$$V_a = 8\text{m/s} = \frac{10\text{m} + 14\text{m}}{2\text{s} + 1\text{s}}$$

Often (but not always) assuming straight ray-path

Interval Velocity

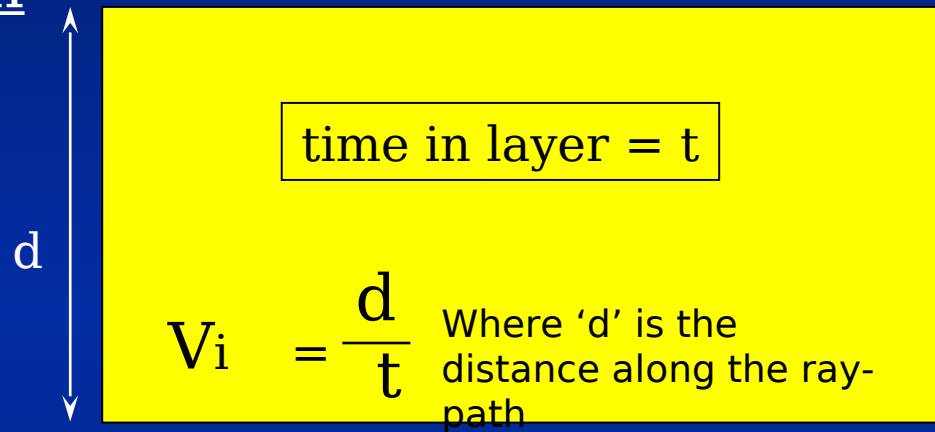
The velocity of an interval in the subsurface measured by determining the travel-time over a depth interval along some ray-path

$$V_i = \frac{d}{t}$$
 Where 'd' is the distance along the ray-path

- Often calculated from stacking velocities assuming horizontal layer and vertical travel paths - Dix's Equation
- **Interval velocity** of a layer has physical meaning – and is mostly independent of what happens 'above' it
- **Average velocity** at some depth depends on what happened above it

Interval Velocity

The velocity of an interval in the subsurface measured by determining the travel-time over a depth interval along some ray-path



$$V_i = \frac{d}{t}$$

Where 'd' is the distance along the ray-path

Dix Equation:
$$V_i^2 = \frac{V_{r2}^2 \times t_2 - V_{r1}^2 \times t_1}{t_2 - t_1}$$

where, V_{r1} and V_{r2} are RMS velocities and t_1 and t_2 are vertical time through layer 1 and 2 respectively.

Often calculated from stacking velocities assuming horizontal layer and vertical travel paths - Dix's Equation

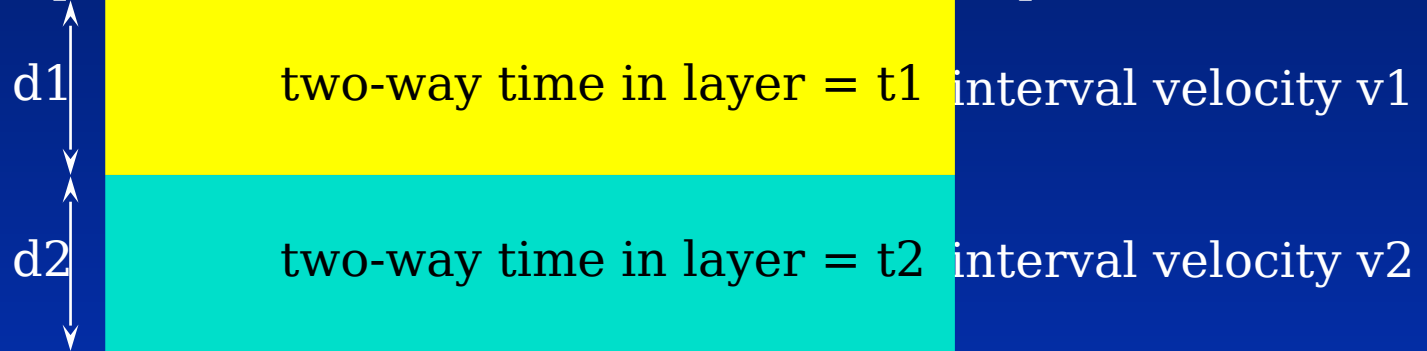
RMS Velocity

The Root Mean Square

velocity

velocity)

(equal to the square root of the average squared

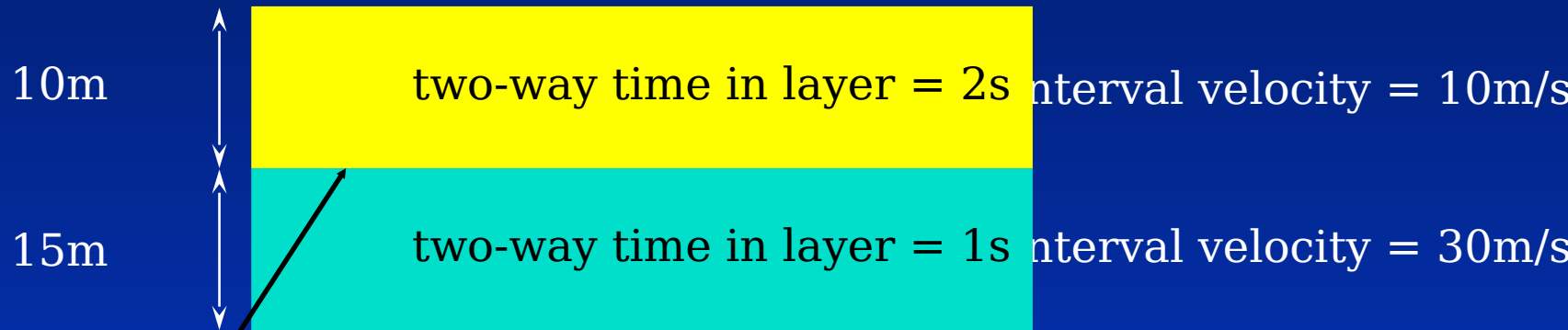


$$V_r = \sqrt{\frac{\sum_{i=1}^n v_i^2 t_i}{\sum_{i=1}^n t_i}}$$

Where, V_i = interval velocity of the i th depth or time interval
 t_i = two-way time through i th depth or time interval

It is not a simple linear velocity. It reflects the fact that the energy is on the *curved shortest time* path.

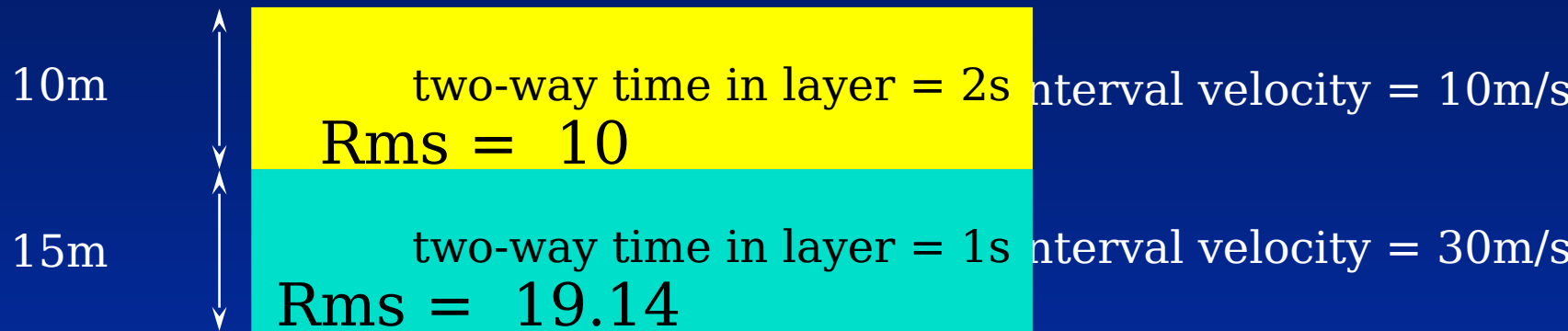
RMS Velocity



$$V_r = \sqrt{(100 \times 2) / 2} = 10.0$$

$$V_r = \sqrt{((100 \times 2) + (900 \times 1)) / 2} = 19.14$$

Interval Velocity of layer using the RMS velocities



Dix Equation:

$$V_i = \frac{\sqrt{V_{r2}^2 \times t_2^2 - V_{r1}^2 \times t_1^2}}{t_2 - t_1}$$

where, V_{r1} and V_{r2} are RMS velocities and t_1 and t_2 are vertical time from the surface to the bottom of layer 1 and from the surface to the bottom of layer 2 respectively.

$$V_i = \frac{\sqrt{((19.14^2 \times 1.5) - (10.0^2 \times 1))}}{0.5} = 30 \text{ m/s}$$

Velocity Definitions Continued

- **NMO velocity** is the velocity used to correct for normal moveout (NMO), i.e. to make primary reflections on CMP gather records occur at the same time on all traces.
- For horizontal or gently dipping layers, NMO velocity = RMS velocity.
 - If we know the RMS velocity we can calculate the interval velocity
- **Stacking Velocity** is the velocity chosen by the analyst and should give the optimum CMP stack output when used for NMO corrections

Stacking velocity is whatever the analyst chooses!

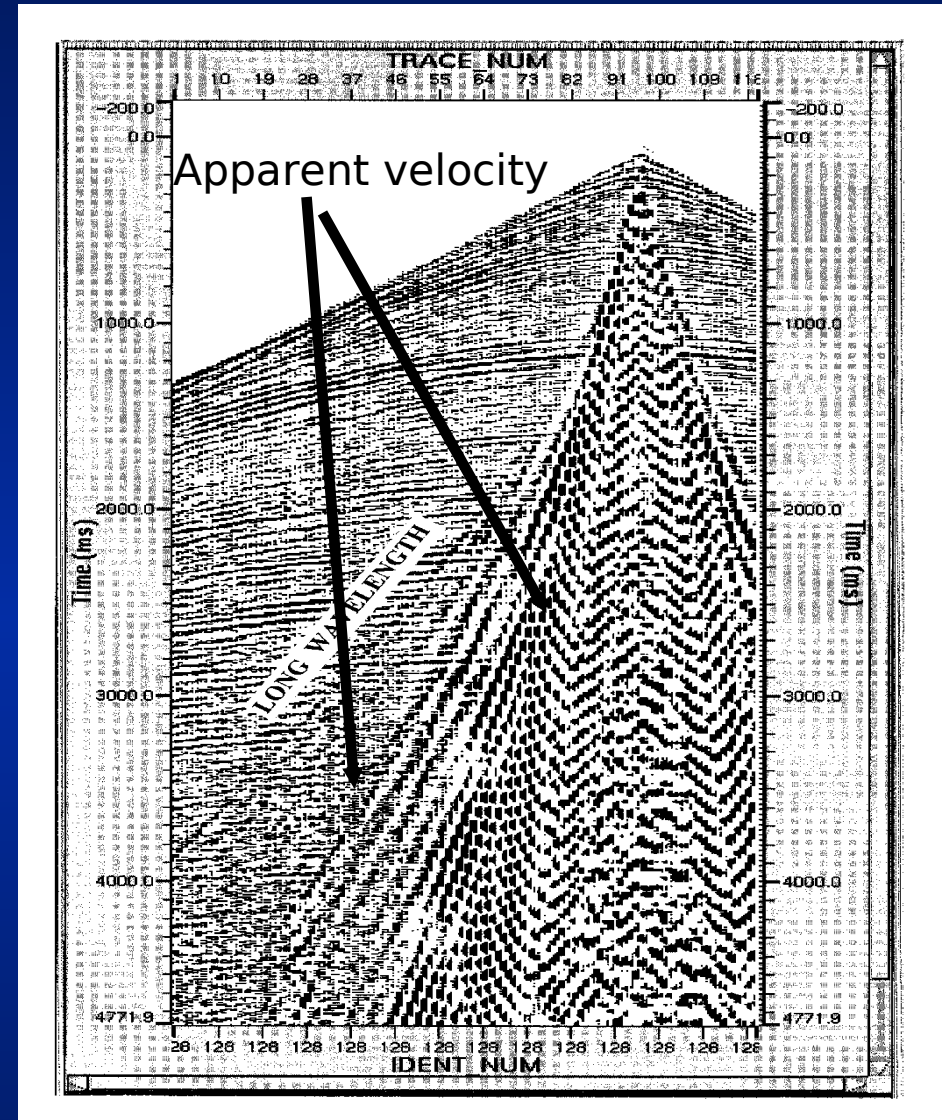
NMO velocities relies/assumes events are HYPERBOLIC

Apparent Velocity

- The velocity which a wavefront appears to have along a line of geophones
- Different to the true velocity if the wavefront strikes the receivers at an angle

$$V_{\text{app}} = V_{\text{true}} / \sin \theta$$

where θ = angle that wave-front makes to receivers. Also known as horizontal phase velocity



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Apparent velocity is
greater or equal to true

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- **Define the term 'NMO correction'**
- **Produce a diagram that shows how a single primary event on a CMP gather would appear for each of the following: no NMO correction, NMO correction using too high velocity, NMO correction using too low velocity, NMO correction using correct velocity**

NMO (Normal Moveout) Velocity

The variation of reflection arrival time due to variation in source - receiver offset.

This variation in arrival time is hyperbolic on a CMP gather

$$t_x^2 = t_0^2 + X^2 / V^2$$

In the presence of dip, the NMO equation is modified :

$$t_x^2 = t_0^2 + X^2 \cos^2 \theta / V^2$$

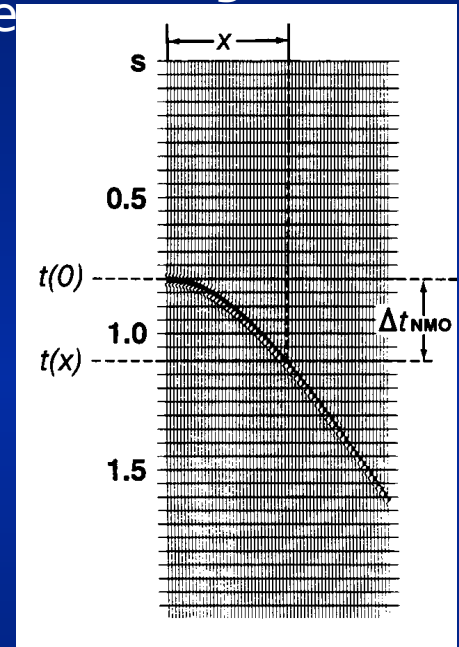
The moveout correction Δt is the time correction applied to each offset

$$\Delta t = t_x - t_0$$

$$\Delta t = \sqrt{t_0^2 + \frac{X^2}{V^2}} - t_0$$

t_x = travel time at offset x
 t_0 = travel time at zero
 X = offset
 V = NMO velocity
 θ = angle of reflector to horizontal

CMP gather

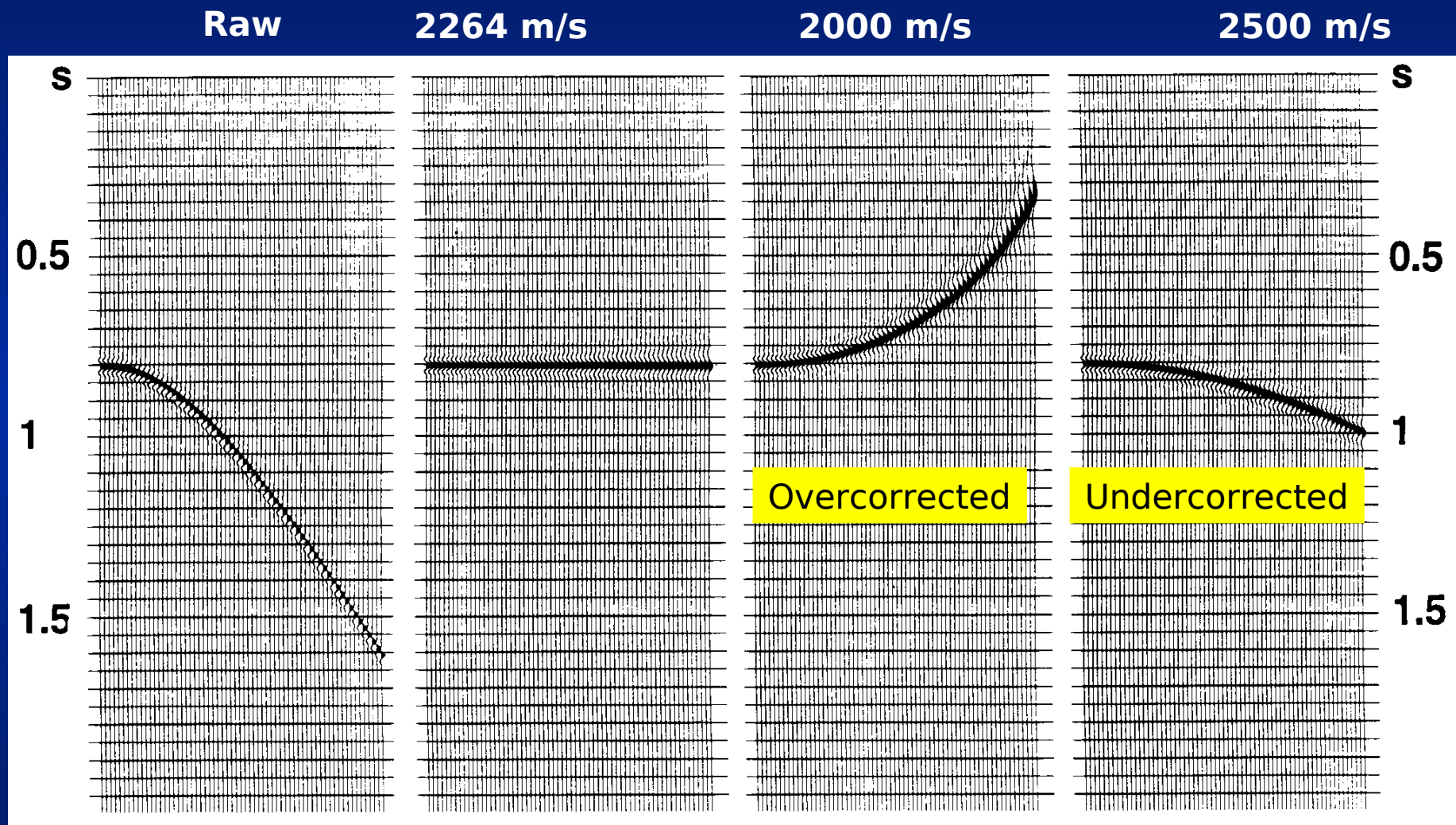


NMO Application

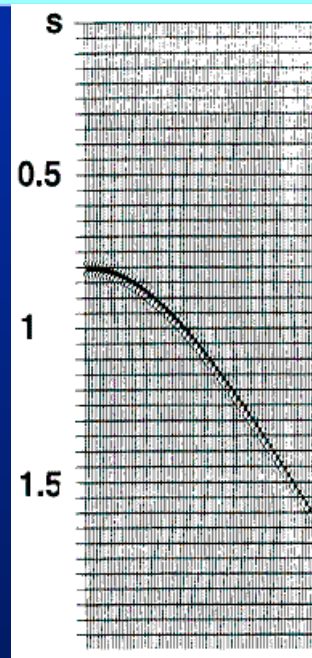
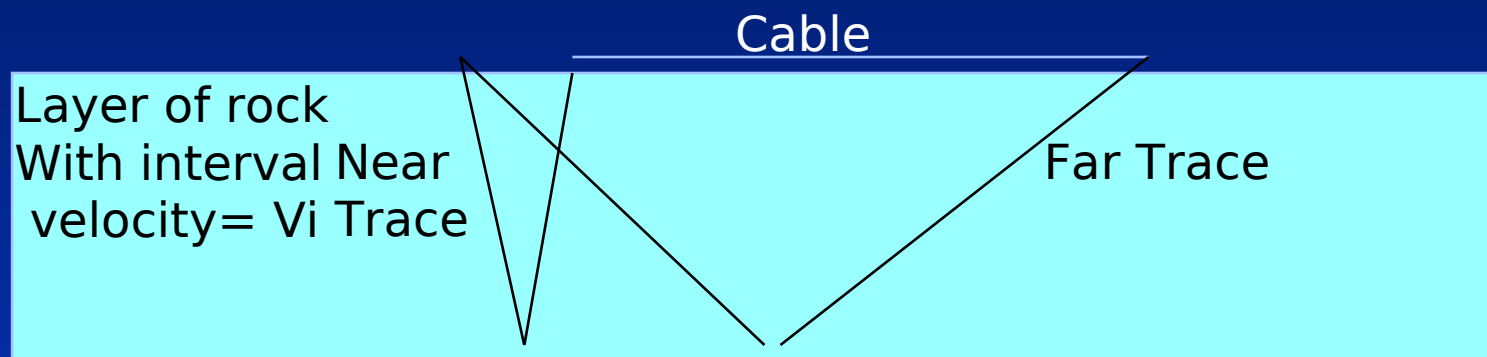
- NMO is applied 1 trace at a time
- Input traces can be in any order
- Input traces need to have CMP number & Offset defined
- For traces with CMP values in between locations a velocity function is calculated using linear interpolation.
- Every sample in a trace is shifted. The amount of the shift is calculated using the

$$t_x^2 = t_0^2 + X^2 / V^2$$

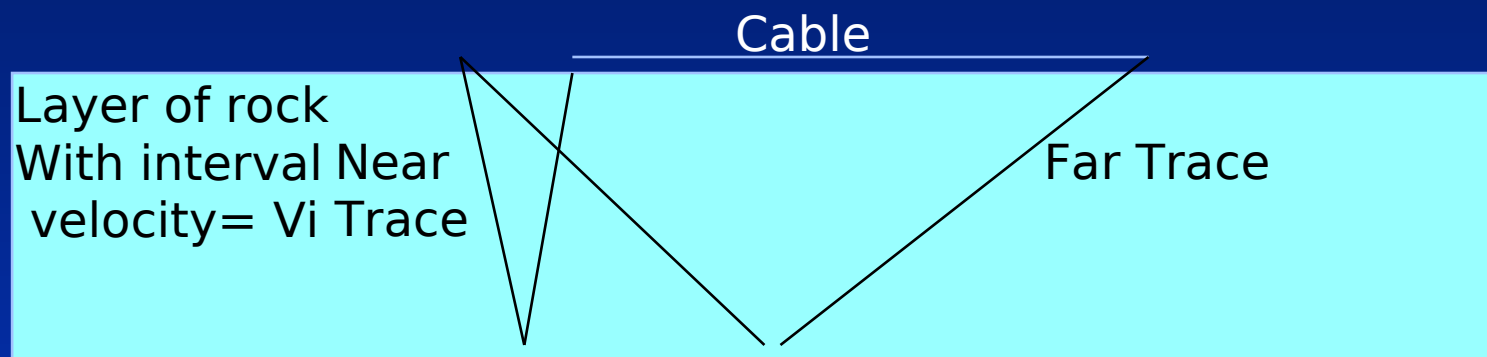
Residual NMO



Residual NMO

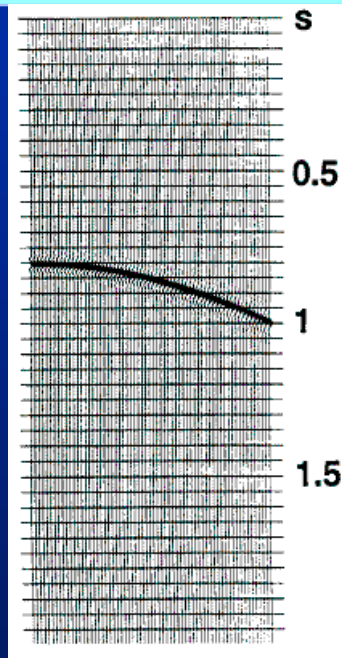


Residual NMO

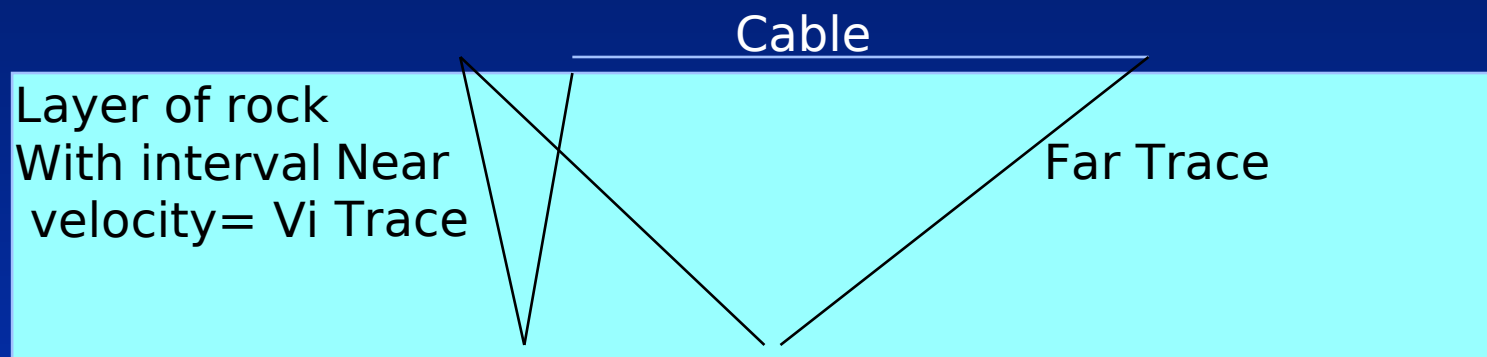


- If we guess that the V_i is very fast the difference in travel times would be small.

- Therefore the NMO correction (I.e. the time shift) of the far offset would be small.
Under Corrected !

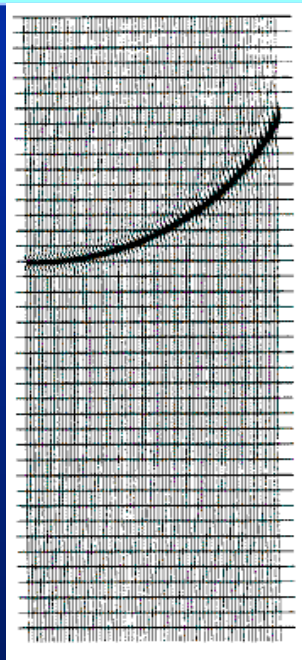


Residual NMO



- If we guess that the V_i is very slow the difference in travel times would be large.

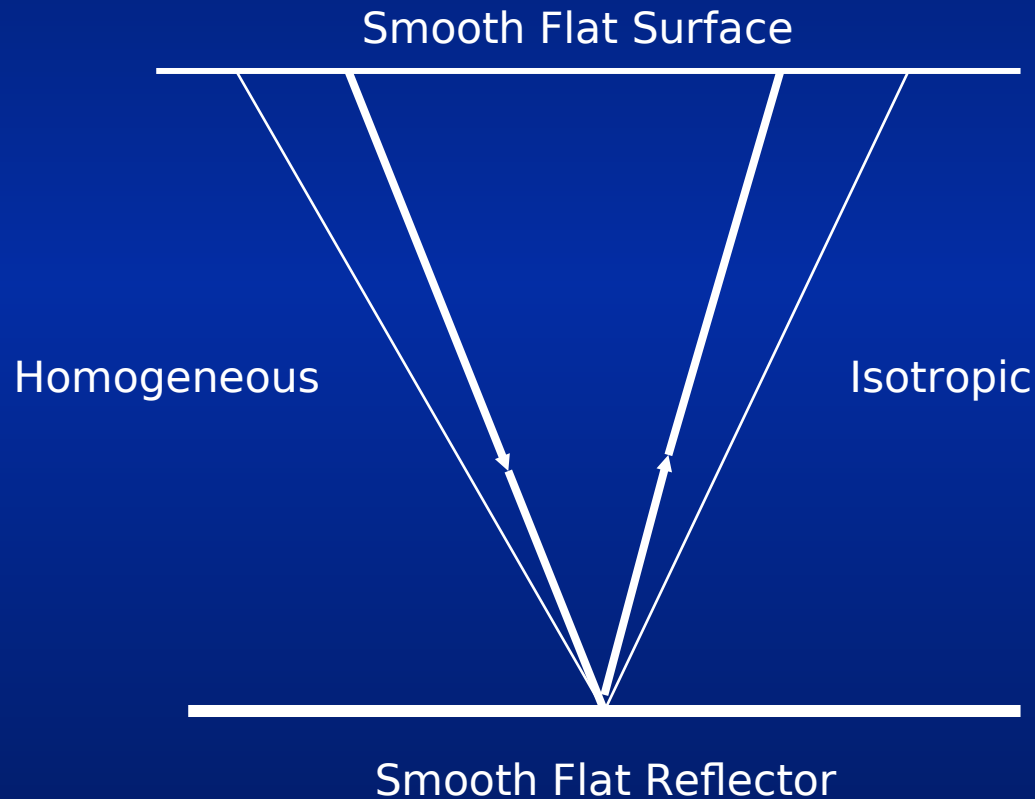
- Therefore the NMO correction (I.e. the time shift) of the far offset would be large.
Over corrected !



Velocity; interval, nmo, stacking, rms, average.....

Can all these different velocities be the same ?

Yes



Uniform Single Layer

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- Define the term 'NMO stretch'

NMO Stretch

This is a frequency distortion by which events are shifted to lower frequencies as a result of the NMO

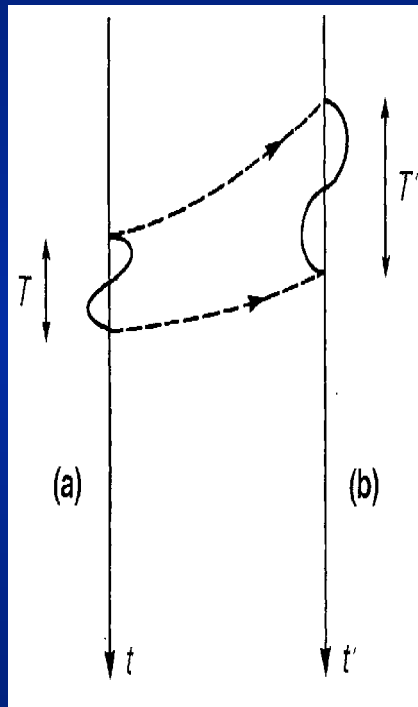


Fig-1

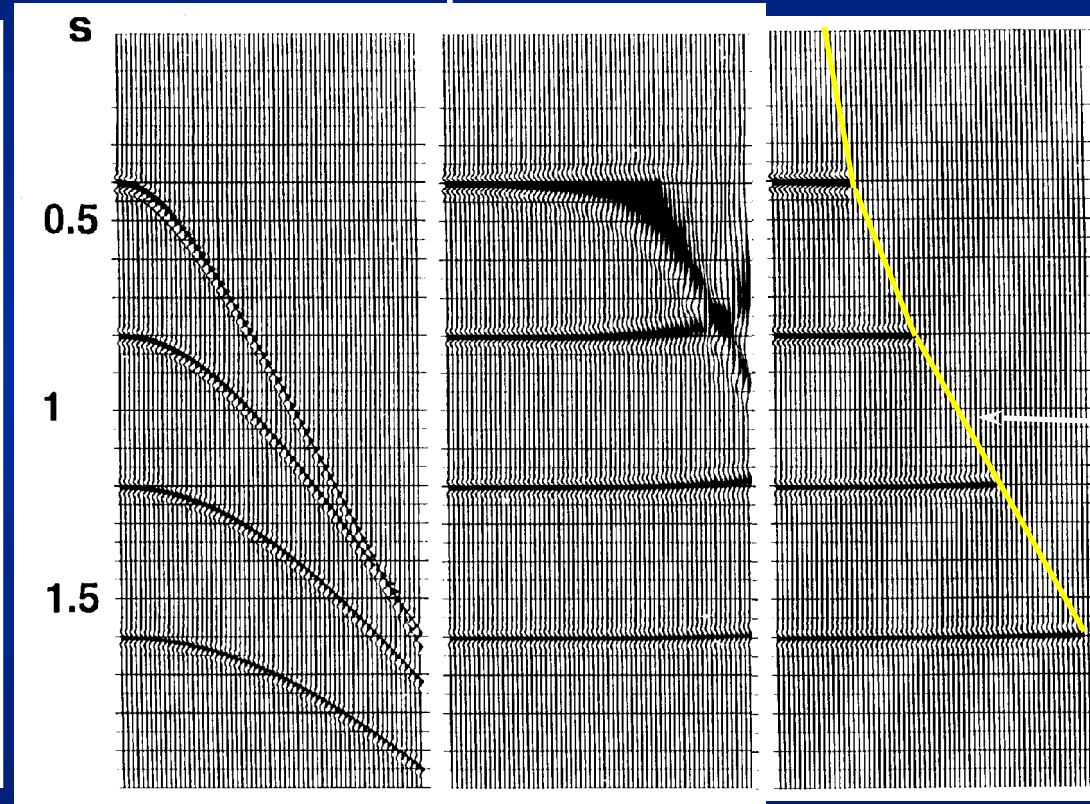


Fig-2

NMO Stretch is generally seen at large offsets and shallow times.

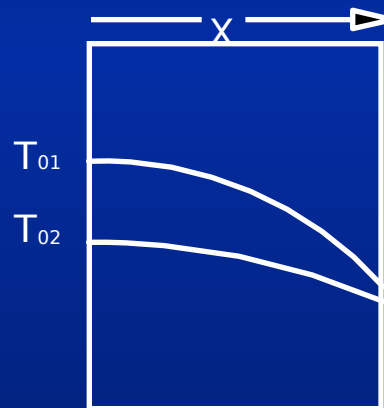
NMO Stretch - An Example

Let's look at an uncorrected CMP gather.
Events 1 and 2 are close together in the shallow section and the same velocity has been picked for both.

$$T_{01} = 0.300s \quad V = 1750 \text{ m/s}$$

$$T_{02} = 0.320s \quad V = 1750 \text{ m/s}$$

$$X = 2400m$$



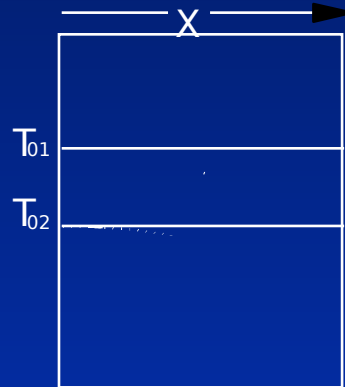
$$T_x^2 = T_0^2 + X^2 / V^2$$

$$T_{x1} = 1.404s$$

$$T_{x2} = 1.408s$$

Stretch - Example

Now look at the corrected events.



Before NMO correction

T for event 1 = 1.404s

T for event 2 = 1.408s

After NMO correction:

T for event 1 = 0.300s

T for event 2 = 0.320s

A 4ms separation is now a 20ms one !

The NMO program uses a sinc function to interpolate the "extra" samples.

Mute Definitions

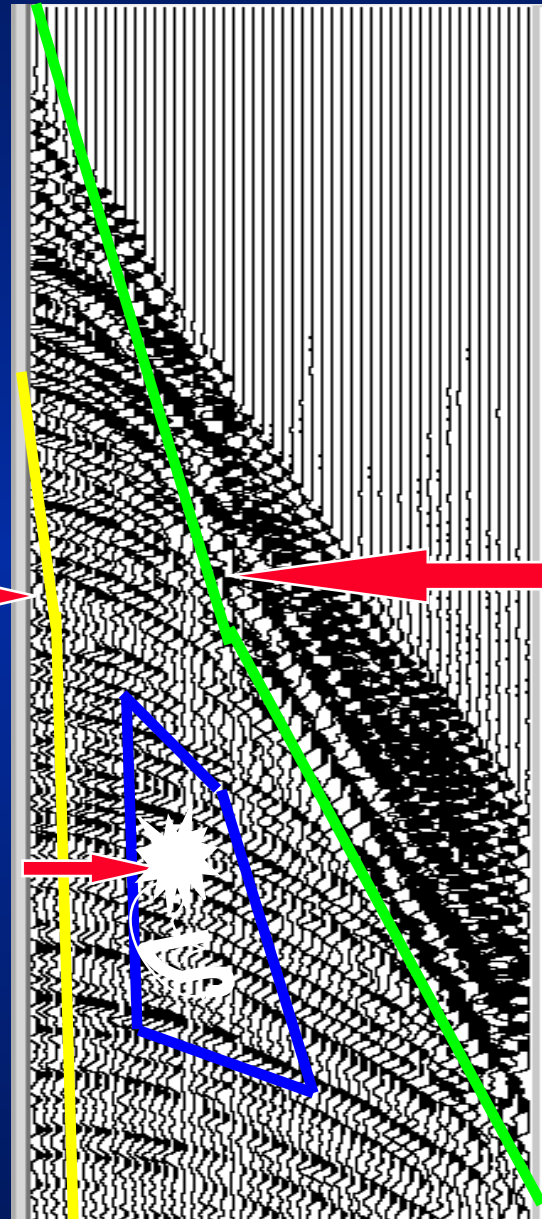
Mute is normally
picked and applied
after NMO corrections

Inside, Tail or
Near Trace Mute

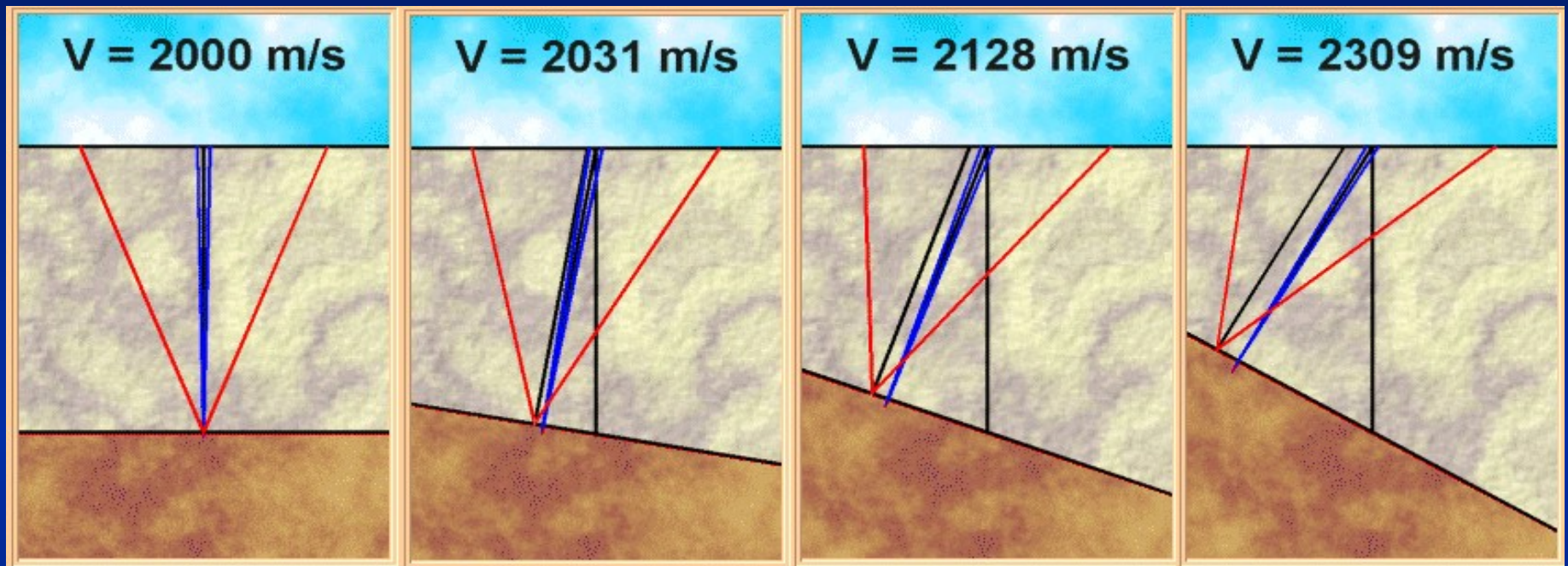
Surgical Mute

Outside or Front Mute

other terms :-
NMO stretch
pre-NMO
First-break mute



Stacking velocity Increases with dip



The difference between the time taken by the **zero offset trace** & **far trace** decreases with dip.

Extrapolate this to a vertical reflector & the times are the same. This would suggest that

The velocity was infinitely fast – I.e. it takes the same time for the energy to travel to the

near offset as it does to the far offset.

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- **Define the term 'knee point' as used in velocity function estimation.**
- **Define the term 'semblance' as used in velocity analysis.**
- **Define the term 'multi velocity function stack' as used in velocity analysis.**
- **Define the term 'constant velocity stacks' as used in velocity analysis.**
- **Define the term 'constant velocity gathers' as used in velocity analysis.**
- **Define the term 'whole line constant velocity stacks' as used in velocity analysis.**
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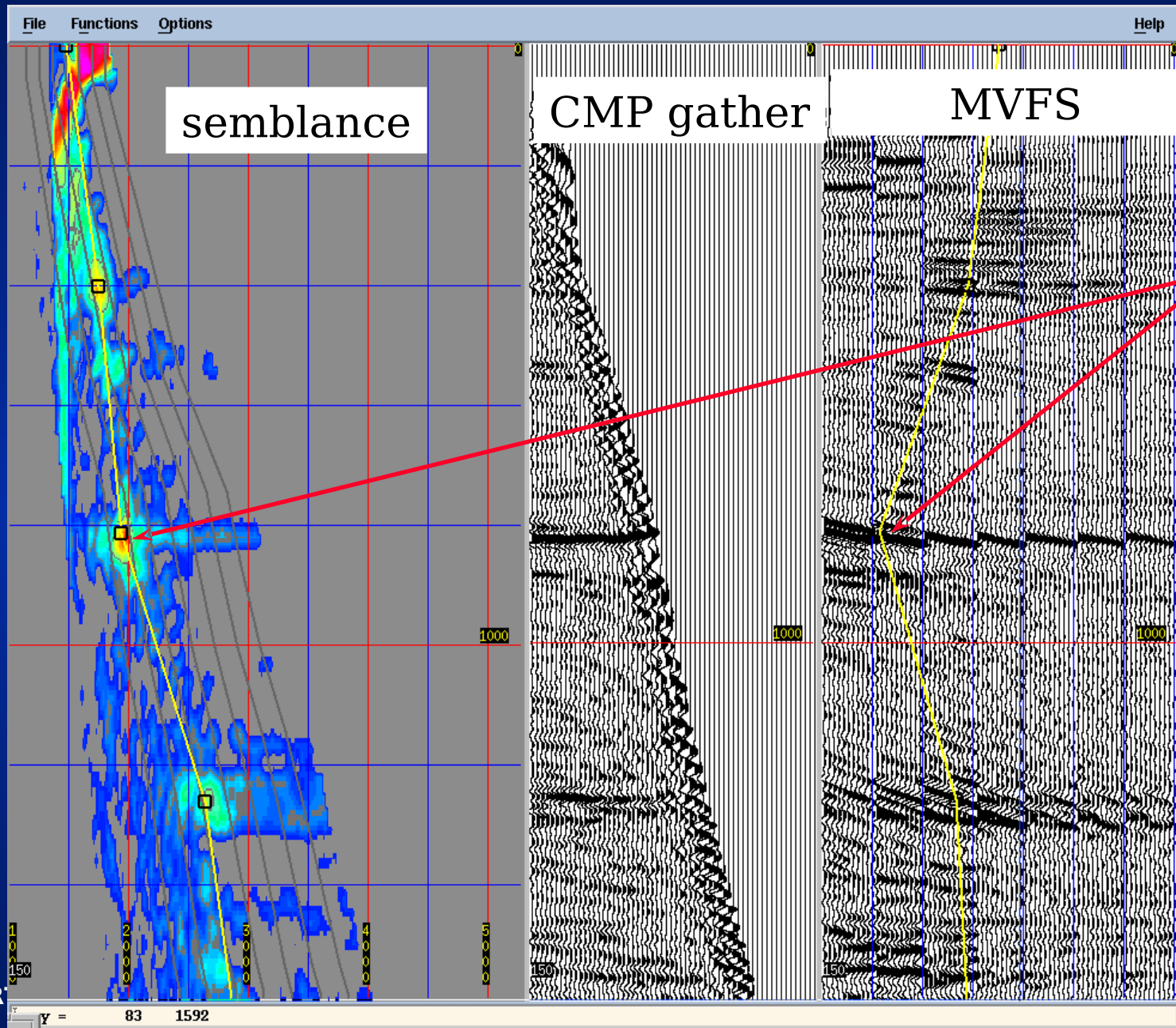
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Velocity Analysis

- This process is looking for hyperbolicity within the data by stacking the data with different (NMO) velocities.
- Through various interpretational tools, the analyst chooses particular velocities (called picks) at particular times at particular CMPs - the STACKING velocity field
- Now is the time for some definitions & equations!

Velocity Analysis Tools



Velocity
'pick'
producing
a 'knee-
point'
on the velocity
function

Velocity Picking ; Omega 2 = INVA Interactive Velocity Analysis

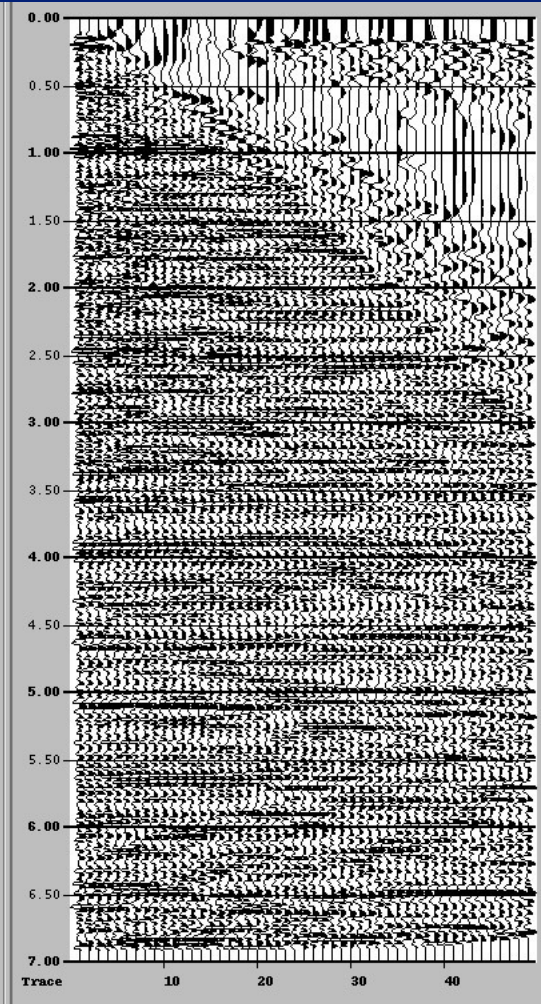
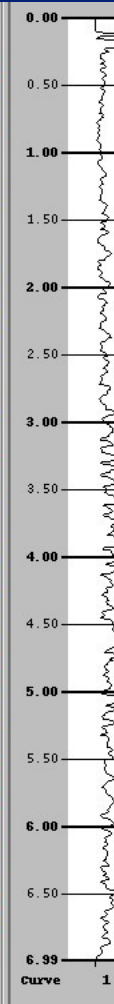
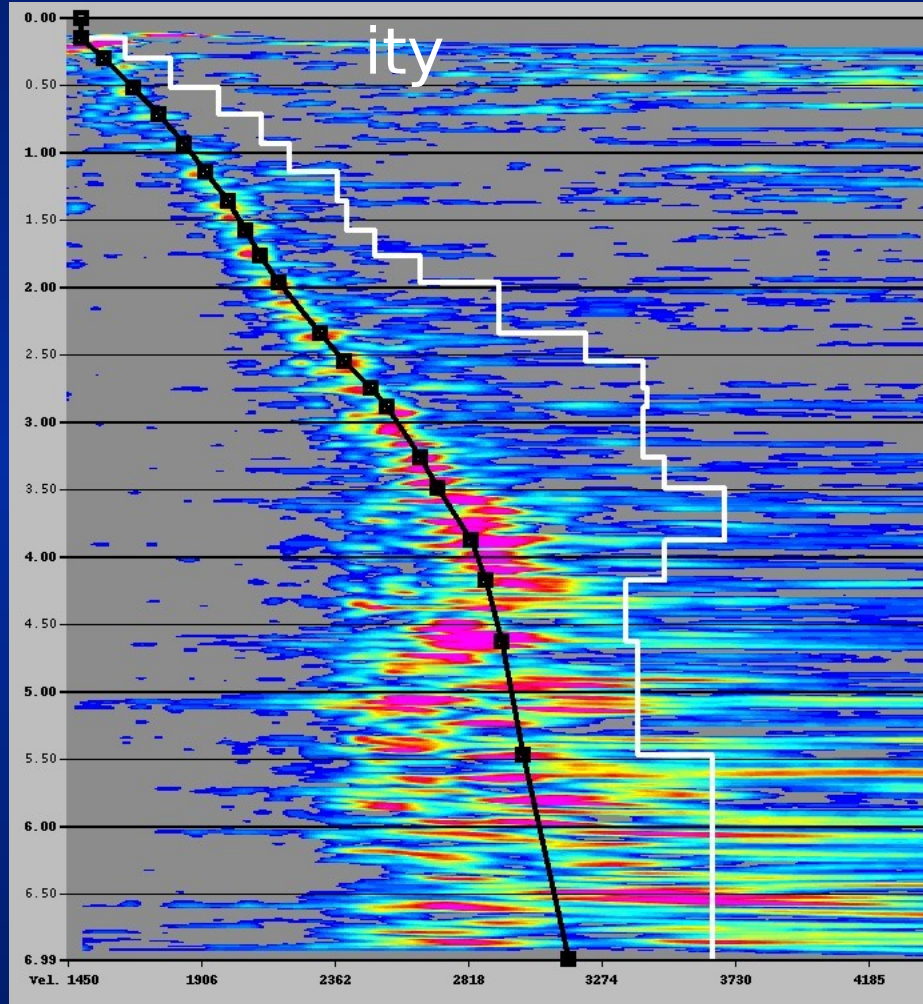
Semblance

Plot

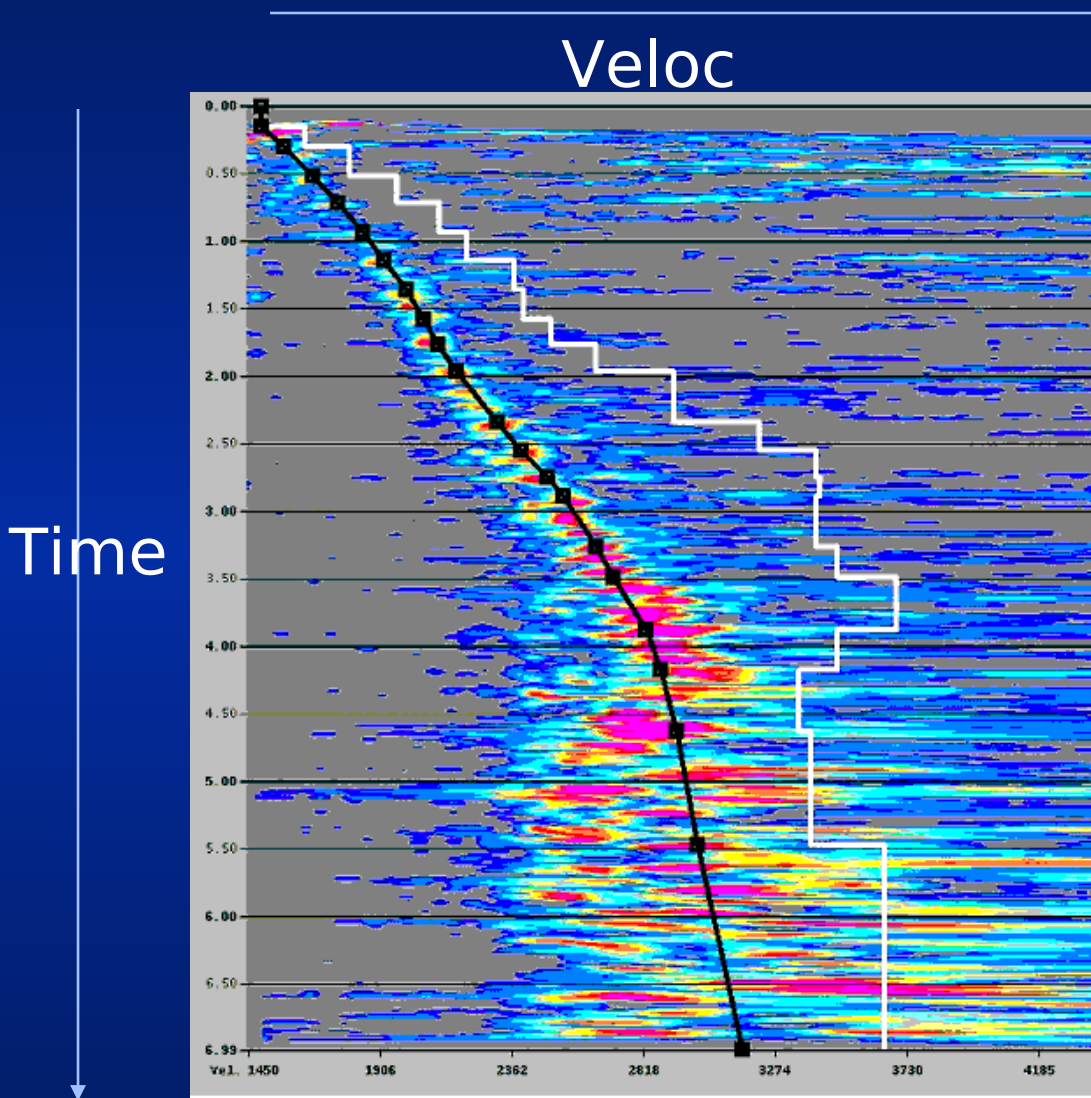
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Veloc

NMO Corrected CMP
Gather



Velocity Picking ; Omega 2 = INVA Interactive Velocity Analysis



The velocity picks for this particular cmp location are saved into a velocity file

Time

Velocity

0

1500

100

1500

140

1620

220

1800

410

The White line is Interval velocity;

The interval Velocities stay constant Between picks

Semblance Analysis

This is a measure of **coherence**.

It is related to the **stack power**.

$$\text{semblance} = \frac{\text{energy of the stacked trace}}{\text{mean energy of the component traces}}$$

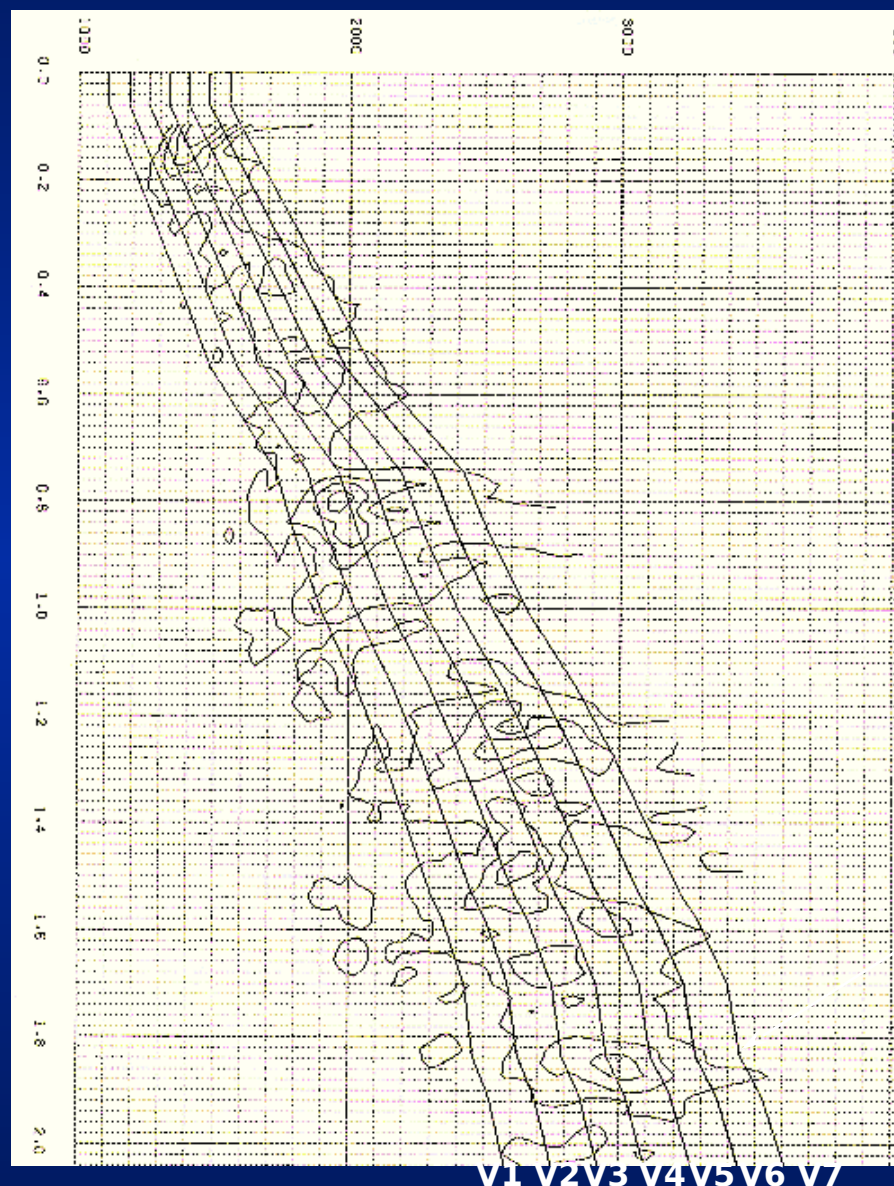
General Procedure :

1. Choose a reference time T_0
2. Choose a value for stacking velocity V (within certain constraints)
3. Compute the semblance of the gather and display it as a function of time and velocity.
4. Repeat for expected range of velocities.

Semblance Analysis

Graph of contoured semblance for various values of time and velocity.

Two or more adjacent CMPs often used in the analysis to increase the signal to noise ratio



variable velocity functions V1 - V7 are as used in the MVF stacked data panels

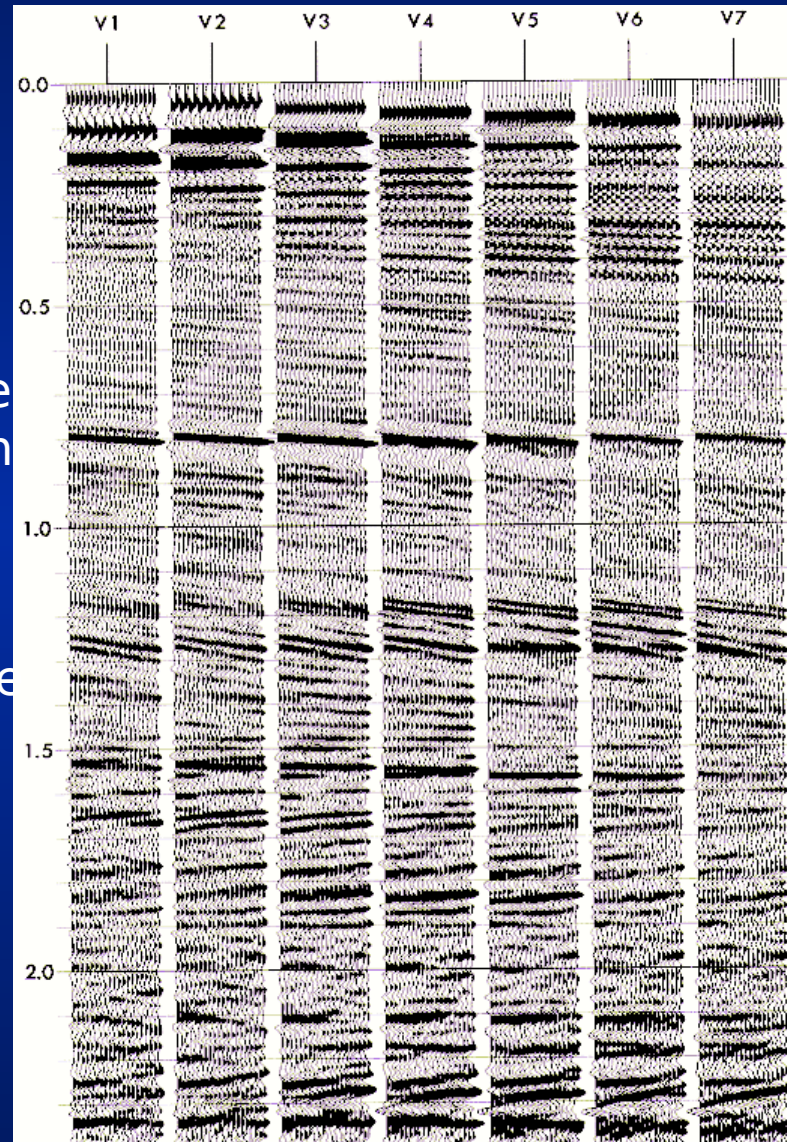
Velocity Analysis; MVFS; Multi Velocity Function Stacks

- Used in INVA to aid Velocity Picking.
- Consist of 21 CMPs centred on the CMP we are picking
- The CMPs are stacked using a best guess velocity function - maybe taken from another survey in the area.
- The same 21 CMPs are stacked again with 105% of the velocities.
- Then again and again with 80% 85% 90% 95% 110%
- All the sets of 21 cmps are displayed side by side in INVA - remember they are the same 21 CMPs but stacked with different velocities.

Multi Velocity Function Stacks

Stacked CMP panels using a different variable velocity function on each panel.

Functions V1-V7 are plotted on the semblance graph.

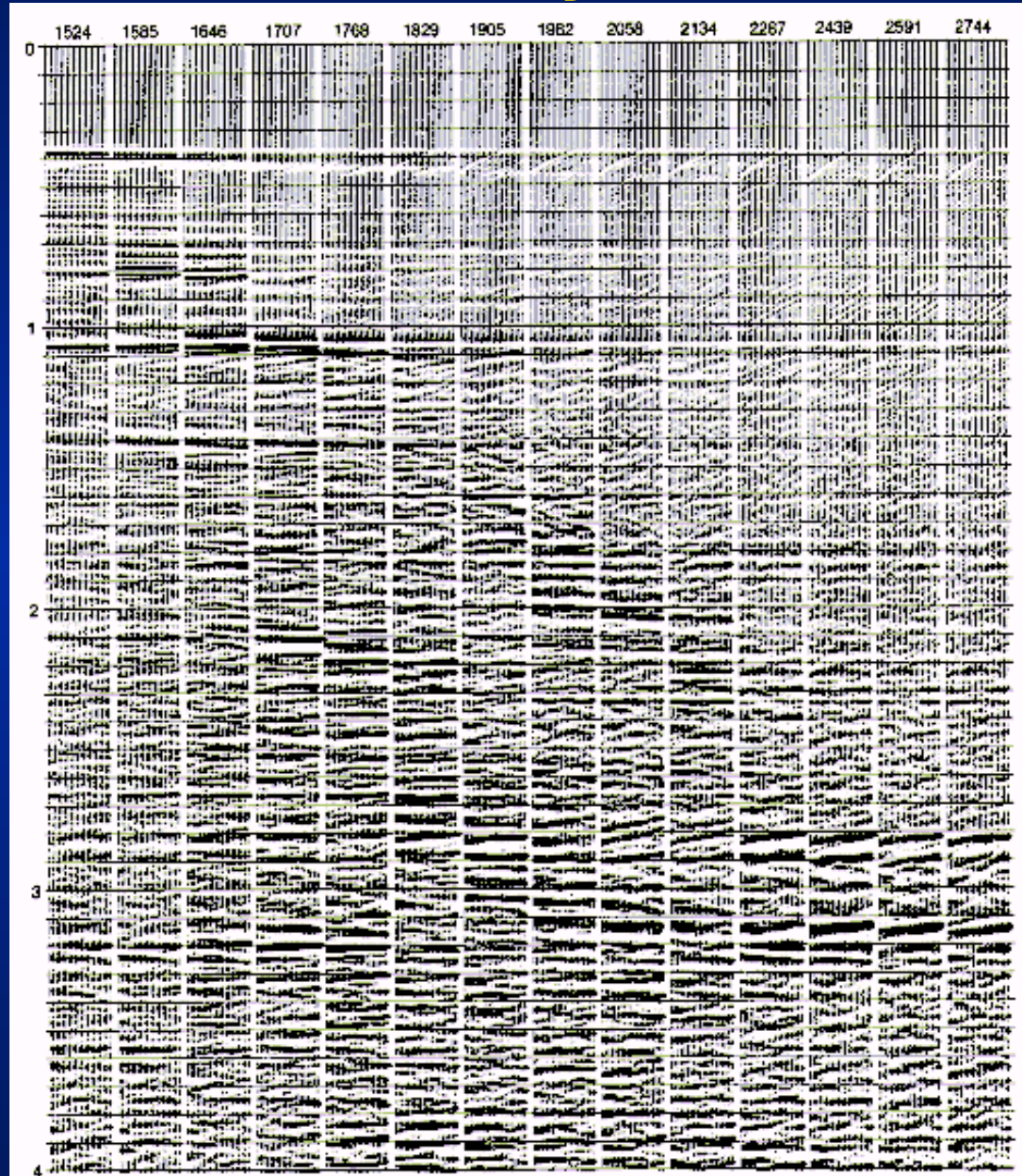


Also called **VVS**
(variable-velocity stacks)

Constant Velocity Stack

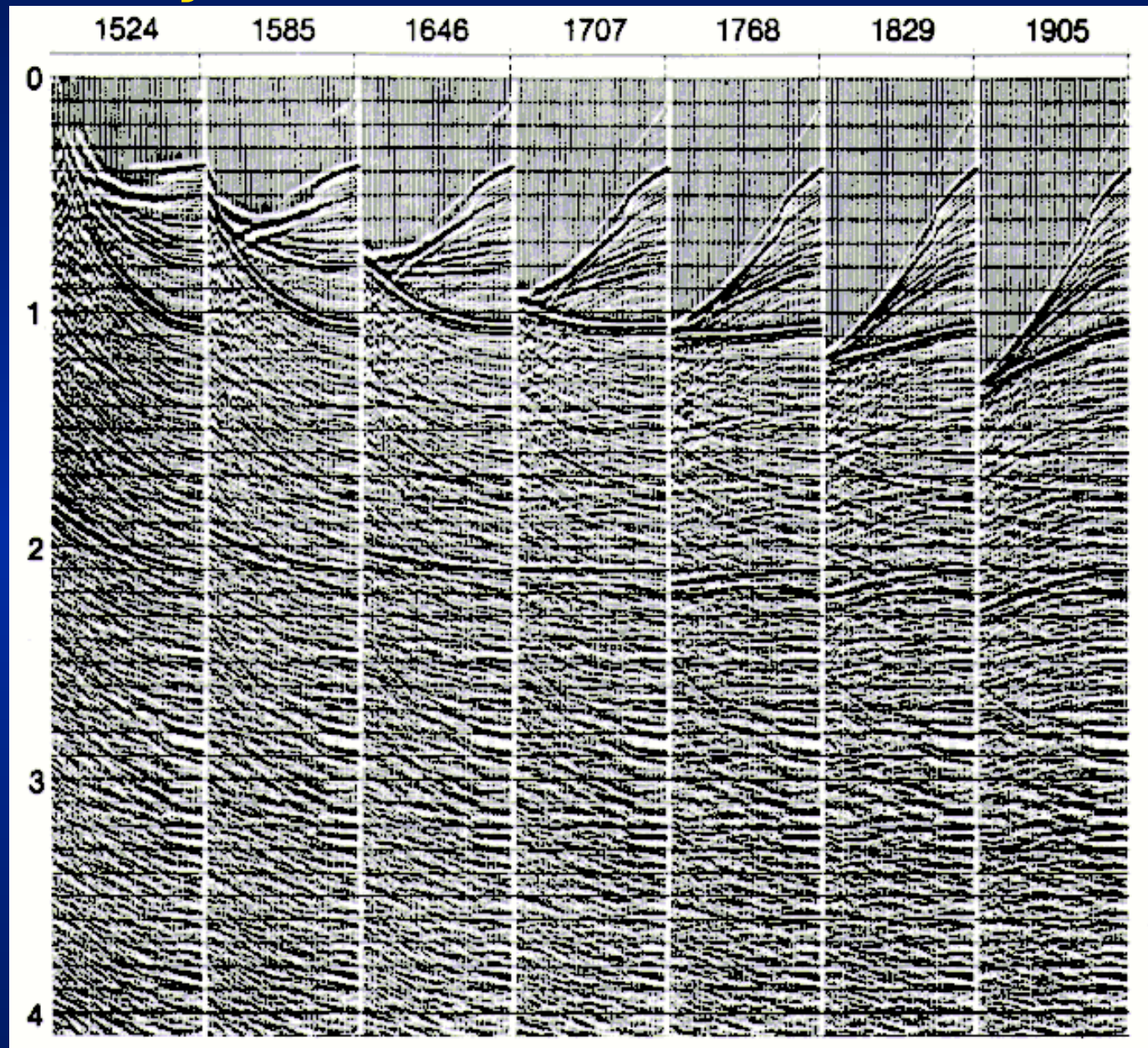
Stacked CMP panels
using a different
constant velocity
on each panel.

Initial Increment: 61m/s
Final Increment: 153m/s



Constant Velocity Gathers

Single CMP
gather after
NMO correction
using a constant
velocity



Some Velocity Analysis Tools (Summary)

Semblance

- picks based on stack power
- needs reasonable signal to noise
- used in conjunction with automatic picking

Multi velocity function stacks (MVFS or VVS)

- picks based on amplitude & continuity of stacked events
- used in areas where velocity trends 'known'

Constant velocity stacks (CVS)

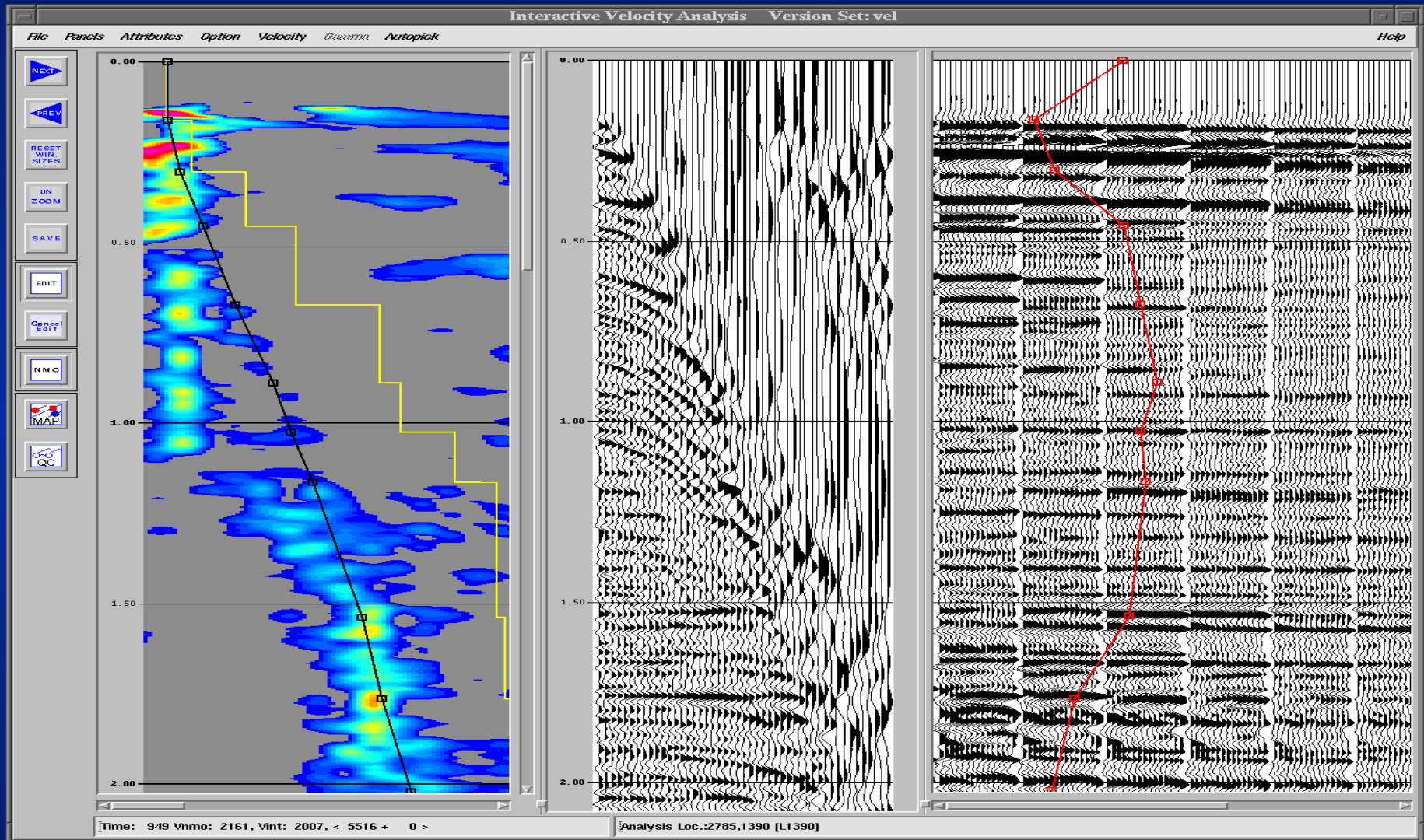
- picks based on amplitude & continuity of stacked events
- more useful in areas where velocity trends are unknown
- easier to use than MVFS when checking for multiples

Multiples

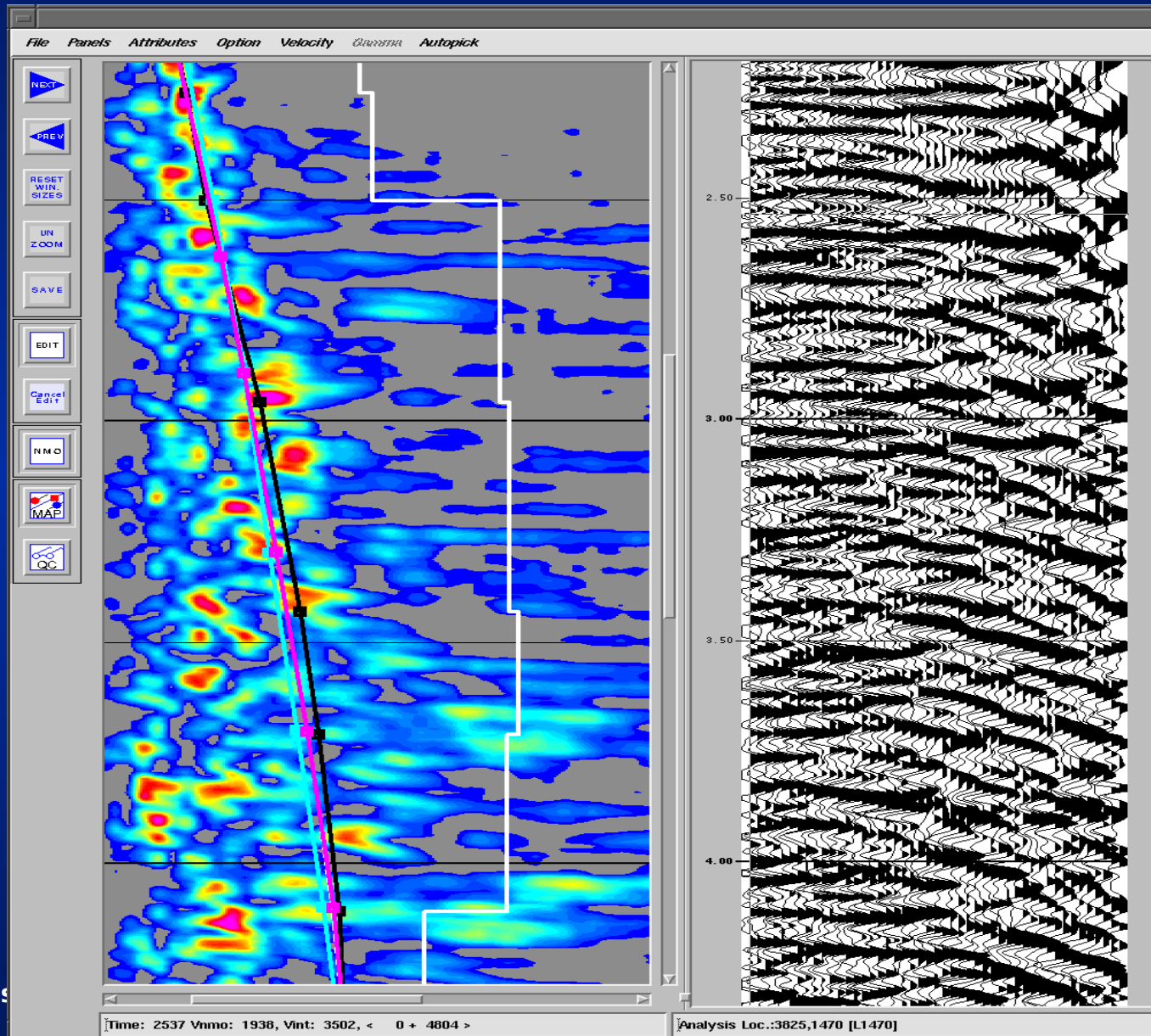
Features to look for when trying to identify multiples :

- **Same velocity or lower velocity than primary**
- **Repetitive in nature i.e. periodic event**
- **Polarity reversal for free-surface multiple**
- **Lower than expected velocity for given time**
- **Events having unexpected dips - multiple or primary?**
- **Events occurring at intervals corresponding to water depth - multiple?**

Water Bottom Multiples



Peg Leg Multiples

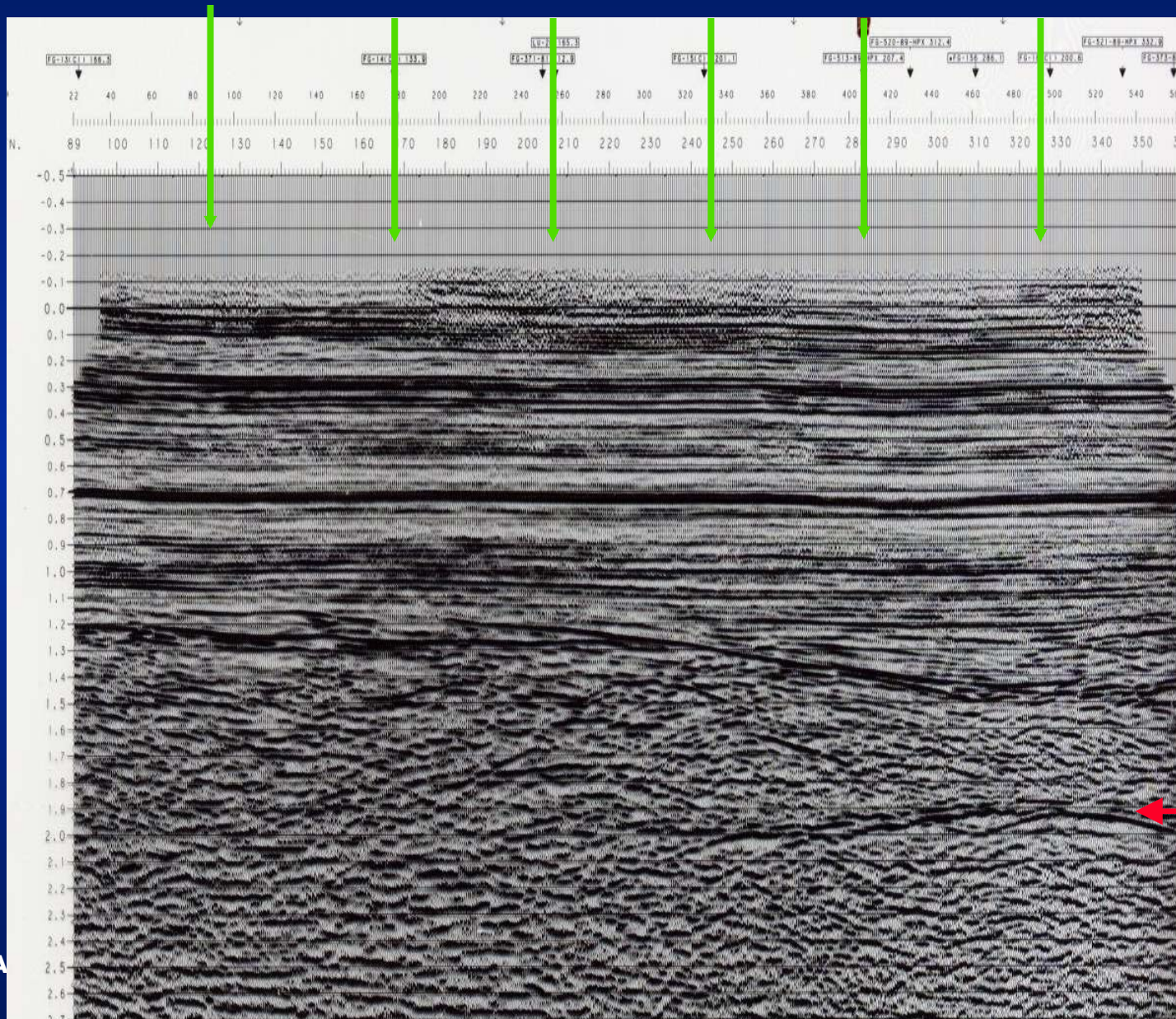


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2004

Factors controlling Analysis Locations

- Lateral variation in velocities for whatever reason(s)
- Geological structure - dips, faults, anticlines, synclines etc
- Fold of stack
- Continuity and noise
- Representative areas of survey (e.g. 2D line intersections)
- Client target zones
- Interpolation errors - control points

Choosing Locations on a Stacked Section



DP STA
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Picked velocity file;

ave 6 location on your line your finished velocity would look like

CMP 100	CMP 250	CMP 400	CMP 550	CMP 700	CMP 850
Time	Time	Time	Time	Time	Time
Velocity	Velocity	Velocity	Velocity	Velocity	Velocity
0	0	0	0	0	0
1500	1500	1500	1500	1500	1500
100	80	70	100	120	100
1500	1600	1600	1550	1560	1500
140	140	140	200	140	160
1620	1800	1620	1620	1620	1620
360	300	220	400	220	220
1800	1900	1800	1800	1800	1800
500	410	410	410	410	410
2020	2020	2020	2020	2020	2020
800	800	800	800	800	800
2300	2300	2300	2300	2300	2300
2000	1500	1500	1500	1500	1500
2800	2800	2800	2800	2800	2800

DP START Oslo

Methods of Velocity Picking and Interpolation

- Conventional
 - picks at each location may be 'random'
 - additional 'picks' interpolated if necessary
- Horizon consistent
 - same events picked at each location
 - easier to maintain velocity trend
 - additional events 'inserted' if necessary
- Isotime consistent
 - picks at the same times on every location

All locations eventually after interpolation will have picks at common times (i.e. same no. of 'picks' per location).

Must be one or other to build 3D velocity field.

Velocity Inversions

Generally expect the stacking velocities to increase with time.

However, provided interval velocities are not unreasonable as a consequence, a reduction in velocity (**velocity inversion**) may occur in certain circumstances.

For example:-

- Where a thick clastic rock is overlain by thick carbonate, basalt etc
- Overthrusting has occurred
- Below salt diapirs
- Change from oil/water sands to gas sands

Q.C. of velocity field

During and after velocity picking Q.C. of the picks may be performed using a number of techniques/products, for example -

- Iso-velocity display
- NMO corrected CMP gathers
- Comparison of brute vs revised velocity stack
- Well-log velocity information
- Velocity Time Slices (for 3D Velocity field only)

IVP iso-velocity display

